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ORIGINAL ARTICLE

Joint Gap Changes with Patellar Tendon Strain and Patellar Position During TKA

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Abstract Balancing of the joint gap in extension and flexion is a prerequisite for success of a total knee arthroplasty. The joint gap is influenced by patellar position. We therefore hypothesized the state of the knee extensor mechanism (including the patellar tendon) would influence the joint gap. In 20 knees undergoing posterior-stabilized type total knee arthroplasties, we measured the joint gap and the patellar tendon strain from 0° to 135° flexion with the femoral component in position. When the patella was reduced, the joint gap was decreased at 90° and 135° (by 1.9 mm and 5.5 mm, respectively) compared with the gap with the patella everted. The patellar tendon strain increased with knee flexion. Patellar tendon strain at 90° flexion correlated with the joint gap difference with the patella in everted and reduced positions. This suggests that in addition to the collateral ligaments, the knee extensor mechanism may have an influence on the joint gap. Therefore, accounting for extensor mechanism tightness may be important in achieving the optimal joint gap balance during total knee arthroplasty.

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Each author certifies that his or her institution has approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

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Level of Evidence: Level IV, therapeutic study. See the Guidelines for Authors for a complete description of levels of evidence.

Introduction

Achieving correct soft tissue balance of the knee is fundamental to the success of TKA [23], and an equal joint gap during extension and flexion is a prerequisite for satisfactory soft tissue balance [9, 10, 21]. In addition, equality of the distance from the femoral component to the tibial surface (the joint gap) throughout the full range of knee motion prevents liftoff of the femoral component and theoretically assists in obtaining the proper contact pressure and kinematics. However, the flexion gap reportedly increases after resection of the posterior cruciate ligament (PCL) during posterior-stabilized (PS) TKA [12, 17].

Conventionally, the joint gap is assessed with the patella in the everted position during TKA, but having the patella everted is not anatomic and does not correspond with the postoperative state of the knee. In fact, patellar eversion increases valgus alignment during soft tissue balancing [15] and affects mediolateral distribution of the tibiofemoral contact forces [4]. However, with minimally invasive surgery [22], the patella is not everted and the joint gap must be assessed intraoperatively with the patella in the reduced position.

Matsumoto et al. measured the joint gap using their own tensor device when performing TKA and showed the gap during flexion was smaller with the patella in the reduced position than with the patella in eversion [16]. The knee extensor mechanism (patellar tendon-patella-quadriceps complex) elongates with knee flexion and pressure on the patellofemoral joint changes with the knee flexion angle

[14]. These facts suggest the knee extensor mechanism may influence the femorotibial joint gap. Thus, in addition to the effects of the ligaments and capsular soft tissues, we suggest that the influence of the extensor mechanism also may need to be included when considering the joint gap.

We hypothesized the patellar tendon strain would increase with passive knee flexion. We then hypothesized the increased strain would decrease the joint gap when the patella is reduced or the knee is flexed.

Materials and Methods

We made within-subjects measurements of the joint gap and patellar tendon strain during TKA and analyzed the relation between these parameters with varying degrees of knee flexion and with the patella everted and reduced. We implanted 17 consecutive patients (20 knees) with a PS TKA using a NexGen LPS-flex (Zimmer, Warsaw, IN). There were two men and 15 women with a mean age of 68.0 years (range, 44–84 years). Our power analysis indicated 20 knees had sufficient power (greater than 80% power) to detect a presumed meaningful difference (3 mm) in joint gaps with the patella everted and reduced. Osteoarthrosis was the underlying disease in 12 knees of 11 patients and rheumatoid arthritis was the disease in eight knees of six patients. The average preoperative maximum extension angle of the knee was −20.5° (range, −60°–0°) and flexion angle was 92.5° (range, 20°–120°). The average preoperative femorotibial angle based on measurements from a standing weightbearing anteroposterior radiograph of the lower extremity at maximum extension was 180.1° (range, 165°–192°). Our institution ethics committee approved the human protocol for this investigation; we obtained informed consent from each patient for participation in the study.

We performed all operations with a measured resection technique. The knee was exposed through a medial parapatellar approach. We performed distal femoral osteotomy perpendicular to the mechanical axis of the femur. The rotational position of the femoral component was determined based on the epicondylar axis of the femur with anterior reference for anteroposterior sizing. We made the proximal tibial cut perpendicular to the mechanical axis of the tibia in the frontal plane with a posterior tilt of 7° in the sagittal plane. After the bone cuts had been completed, we performed standard soft tissue balancing using a spacer block. All measurements were performed under general anesthesia.

After bone cuts and standard soft tissue balancing, we measured the joint gap with the femoral component in position. We used the tensor device developed by Matsumoto et al. [16] for measuring the joint gaps. This device consisted of two plates that were connected to the main body by the offset arm. The upper plate was free to seesaw under the relative balance between medial and lateral soft tissues and had a post at its center to fit the intercondylar space of the femoral component. The lower plate was fixed with pins to the center of the proximal tibia. We applied a constant 40-pound distracting force between the two plates (Fig. 1) provided by a ratchet-type hex wrench, which limited applicable force at 40 pounds. The 40-pound distracting force was chosen based on previous studies [12, 16] regarding joint gap measurement during surgery and to maintain the integrity of the bone and soft tissues. The width of the joint gap was defined as the center distance between the upper side of the seesaw plate and the underside of the lower plate. Assessment was performed at 0°, 10°, 45°, 60°, 90°, and 135° flexion, which were measured by a goniometer. The joint gap at 0° flexion was measured while the thigh and the leg were horizontal on the operating table. The gap measurement in knee flexion was performed with the heel on the table and the thigh held by an assistant to minimize the effect of the weight of the thigh. We measured the joint gap with the patella everted first (Fig. 2A) followed by measurement in the reduced position after repair of the medial arthrotomy with a few stitches (Fig. 2B). Data could not be obtained at 135° flexion from two patients because the knees could not be flexed that far.

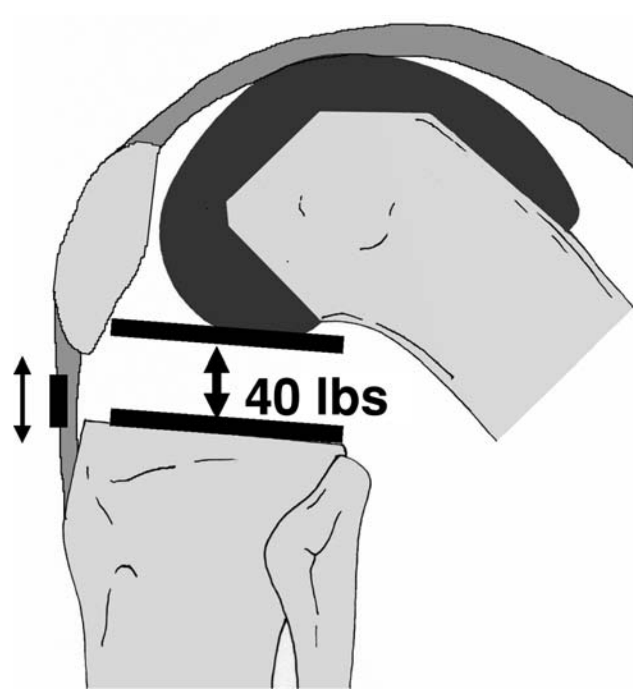

Fig. 1 The joint gap and the longitudinal strain on the patellar tendon (thin arrow) are measured with the femoral component in position under a distracting force of 40 pounds.

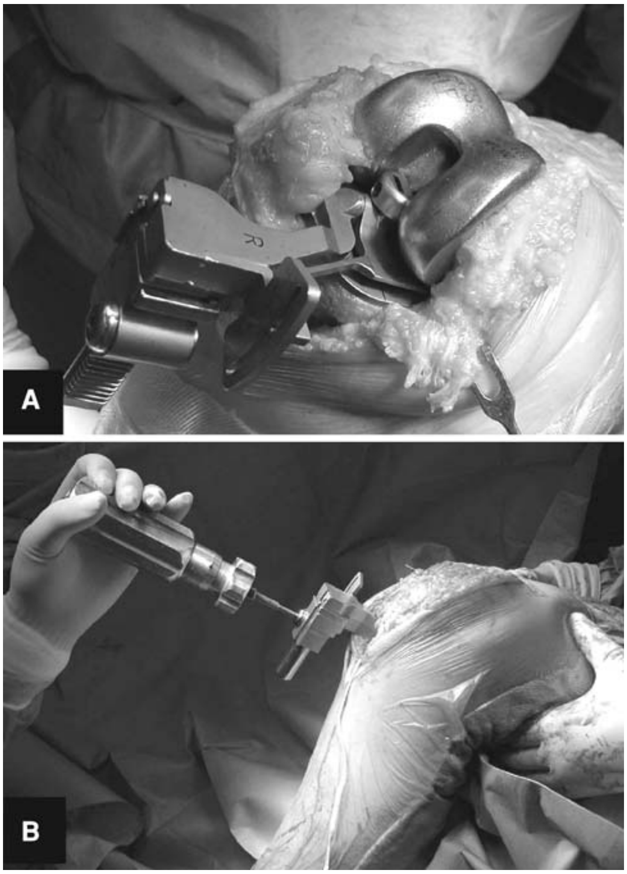

Fig. 2A–B The joint gap is measured with the femoral component in position and either (**A**) the patella everted or (**B**) the patella reduced using the tensor device under a distracting force provided by the ratchet-type torque wrench.

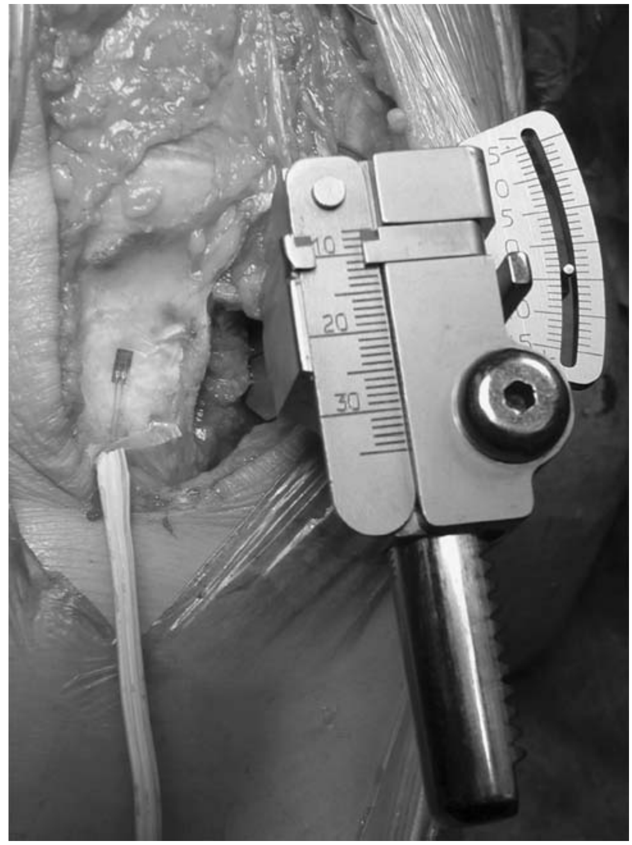

Fig. 3 A minute uniaxial foil strain gauge is glued to the surface of the midportion of the patellar tendon.

We also measured the longitudinal strain on the patellar tendon at the time of each joint gap measurement with the patella in the reduced position using a 5-mm-long minute uniaxial foil strain gauge (KFG-1-120-C1-11L5M3R; Kyowa Electronic Instruments Co, Ltd, Tokyo, Japan). The strain gauge was glued with α-cyanoacrylate monomer to the surface of the midportion of the patellar tendon while the tendon showed adequate tension at 45° knee flexion (Fig. 3), and we analyzed the longitudinal strain on the patellar tendon recorded by the gauge using a sensor interface (PCD-300A; Kyowa Electronic Instruments Co, Ltd). At 0°, 10°, 45°, 60°, 90°, and 135° knee flexion, we recorded the average strain for 5 seconds after tensioning five times with a distraction force of 40 pounds using a ratchet-type wrench. The strain values at each angle of flexion were defined as a change in strain with respect to the strain value at 0° knee flexion with the joint distracting force. After the recording, we carefully removed the strain gauge and the glue from the tendon surface using the scalpel.

We analyzed the relation between the decreases in the joint gap when the patella is reduced (ie, the gap measured with the patella everted minus that measured with the patella reduced) and the patellar tendon strain with the patella reduced at each flexion angle. We also compared the changes in the joint gap with the changes in the patellar tendon strain between flexion angles in reduced patellar position.

Data are expressed as mean ± standard error. We used the paired t-test to identify differences between the gap measured with the patella everted and the patella reduced and the repeated-measures analysis of variance with a Student-Newman-Keuls post hoc test to compare the joint gaps and the patellar tendon strain between flexion angles. We calculated correlation coefficients for the decreases in joint gap versus patellar tendon strain at each flexion angle and the changes in the joint gap versus the changes in the patellar tendon strain between flexion angles. The level of significance was set at $p < 0.05$ for all analyses.

Results

Mean patellar tendon strain increased with increasing knee flexion. The strain was greater at 90° knee flexion than at 0°, 10°, and 45° flexion ($p = 0.005$, $p = 0.013$, and $p = 0.014$, respectively). At 135° knee flexion, the strain

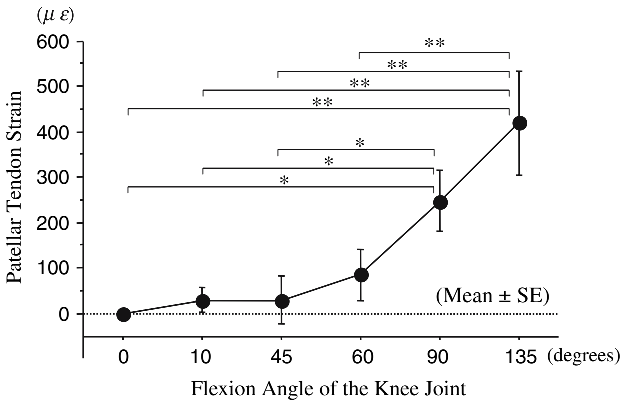

Fig. 4 Mean strain acting on the patellar tendon: the strain increased gradually with an increase of knee flexion. The strain at 90° and 135° flexion was greater (*$p < 0.05$ and **$p < 0.001$, respectively) than at the other angles measured. SE = standard error.

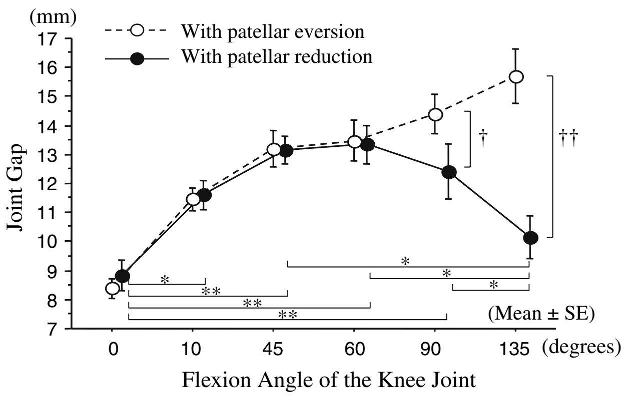

Fig. 5 The mean width of the joint gap with the femoral component in position: with the patella everted, the joint gap at each angle of flexion gradually increases in proportion to the extent of flexion. In contrast, with the patella in the reduced position, the mean width of the joint gap tended to increase until 60° knee flexion and then decreased until at 135° flexion (*$p < 0.05$ and **$p < 0.001$). The joint gap measured at 90° and 135° flexion with the patella reduced was narrower than that measured with the patella everted (†$p < 0.05$ and ††$p < 0.001$). SE = standard error.

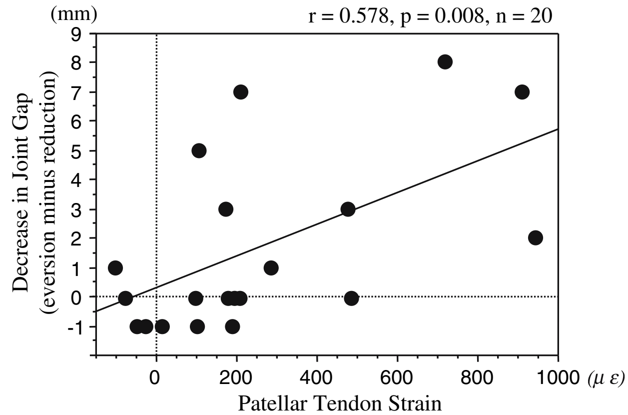

Fig. 6 The relation between the strain on the patellar tendon with the patella reduced and the decrease in the joint gap when the patella is reduced (the gap with the patella in eversion minus that with the patella in reduction) at 90° flexion is shown. There was a positive correlation ($r = 0.578$, $p = 0.008$) between patellar tendon strain and decrease in the joint gap.

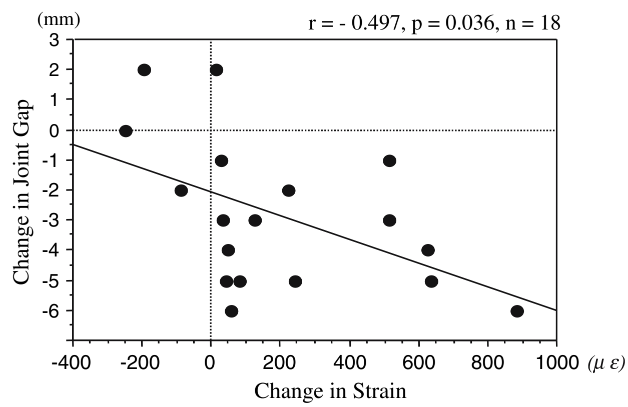

Fig. 7 The relation between the change in patellar strain and the change in the joint gaps from 90° to 135° (that at 135° flexion minus that at 90° flexion) is shown. The width of the joint gap showed a decrease ($r = -0.497$, $p = 0.036$) as the strain on the patellar tendon increased during flexion from 90° to 135°.

was greater than that at 0°, 10°, 45°, and 60° flexion ($p < 0.001$ for all) (Fig. 4).

When the patella was everted, the mean width of the joint gap monotonically increased with increasing knee flexion. However, with the patella in the reduced position, the mean width of the joint gap tended to increase until 60° knee flexion and then decreased until 135° flexion. The joint gap measured at 90° and 135° flexion with the patella reduced was narrower than that measured with the patellar everted (by 1.9 mm and 5.5 mm, $p = 0.038$ and $p < 0.001$, respectively). The joint gap with patella reduction measured at 10°, 45°, 60°, and 90° flexion was wider than that measured at 0° flexion ($p = 0.003$, $p < 0.001$, $p < 0.001$, and $p < 0.001$, respectively). At 135° flexion, the joint gap with the patella reduced was narrower than at 45°, 60°, and 90° flexion ($p = 0.002$, $p = 0.001$, and $p = 0.019$, respectively) (Fig. 5). At 90° flexion, the decrease in the joint gap (ie, the gap measured with the patella everted minus that measured with the patella reduced) correlated with ($r = 0.578$, $p = 0.008$) the mean patellar tendon strain with the patella reduced (Fig. 6). The change in the joint gap from 90° to 135° in reduced patellar position (the mean value at 135° minus the mean value at 90°) negatively correlated ($r = -0.497$, $p = 0.036$) with the change in patellar tendon strain during flexion from 90° to 135° (Fig. 7).

Discussion

Knee flexion gaps are reportedly less with the patella reduced compared with everted in TKA [16]. The knee extensor mechanism therefore likely influences the joint gap in flexion. We hypothesized the decrease in flexion gap with the patella reduced compared with everted and the change in joint gap during knee flexion in the reduced patellar position are associated with increased patellar tendon strain.

One of the limitations of our study is the use of the foil strain gauge, which usually is used to measure the strain of the tissues with a larger elastic modulus [5, 19]. We used the foil strain gauge to avoid possible injury to the patellar tendon by insertion of other types of gauges, and this may partly explain the relatively small strain value observed in the current study [1, 3, 11, 20]. Therefore, we estimated the strain value as the relative value between two strain measurements with a value at 0° flexion as the standard. Another limitation is the strain measurement on the patellar tendon surface. The patellar tendon is not a homogenous tissue [18] and owing to its regional properties, we cannot infer strain throughout the entire tendon. However, currently available data suggest strain increases on the anterior part of the tendon rather than the posterior portion during knee flexion [1, 7]. Because our study is based on the measurements during TKA, we did not know the zero load length of the patellar tendon or amount of force transferred by the patellar tendon and estimated the relative strain value compared with that at 0° flexion. Nevertheless, the results partly clarified the effects of the extensor mechanism on the joint gaps in vivo and should be used as a starting point for future quantitative investigation using models making use of muscle loading conditions. Our data cannot address the question of an optimum joint gap in TKA. In addition to assessment of the joint gap defined by ligaments, additional investigation must take into account the effect of the knee extensor mechanism to establish the optimum joint gap.

We measured the joint gap with the femoral component in position and the patella everted or reduced during PS-type TKA to compare the results of the joint gap and patellar tendon strain. Because measurement of the medial/lateral joint gap [4, 15] could be hampered in the reduced patellar position, we selected center gap as a reliable and measurable gap during surgery. Our findings confirm those of a previous report [16] suggesting joint gaps are smaller with the patella in a reduced position than in an everted position. Furthermore, the data suggest patellar tendon strain is associated with the change in joint gap during knee flexion.

When the conventional flexion gap measured with the patella everted was wider than the extension gap during PS-type TKA, one option is to enlarge the anteroposterior diameter of the femoral component. However, a larger component might cause a marked increase in extensor stretching, and this may further decrease the joint gap during knee flexion with a reduced patella. Our data raise a question regarding whether the conventional method of joint gap measurement with the patella in the everted position is satisfactory and whether it is always ideal for the extension gap to equal the flexion gap. In fact, some studies suggest soft tissue balance is not always achieved during TKA [6, 8]. An excessively large flexion gap may cause flexion instability, although the actual amount of gap that should be considered excessive is unclear and several millimeters of laxity in flexion can be tolerated [8]. Few studies have attempted to accurately identify the appropriate amount of laxity [2], and this should be elucidated in the future.

What are the implications of the extensor mechanism and PCL during PS-type TKA? Posterior cruciate ligament resection during TKA is associated with an increase of the flexion gap with little corresponding increase in the extension gap [12]. Although the primary function of the PCL is to resist posterior tibial translation, beyond 90° flexion, it acts to maintain a stable joint gap between the femur and tibia [12, 17]. Thus, the PCL may act as an important passive stabilizer after knee arthroplasty, especially for maintenance of the flexion gap and stability during flexion. The PCL and patellar tendon are almost parallel to the longitudinal axis of the tibia when the knee is flexed 90° [13]. Therefore, it is likely the patellar tendon and the knee extensor mechanism act to maintain the joint gap when the knee is flexed after resection of the PCL.

Although the collateral ligaments are likely the most important restraints to proximodistal translation of the tibia, the extensor mechanism also is associated with the joint gap during flexion with the patella reduced. The definition of an optimal joint gap therefore should be reconsidered. It is necessary to evaluate extensor mechanism tightness to achieve a satisfactory balance between the joint gaps.

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